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Design of an alarm and risk management in chemistry Some lessons learned from interdisciplinary research[1]

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ABSTRACT : "Chemical runaways" constitute major sources of accidents in chemical processes. In this communication, we underline the lessons we learned from the implementation of the system on an industrial site. Firstly, introduction of the system may be defined as a know-how and technique transfer. Secondly, the interest of the approach of introducing the technical system is not limited to use of the system and its characteristics, but should be extended to all the action conditions. On this basis, we argue that the industrialization of an artefact like the one we have designed should be done with each installation.

KEYWORDS : Chemical runaway, technique transfer, innovation, design and risk, latent errors.

INTRODUCTION

In this communication, we would like to contribute some elements from inderdisciplinary research whose purpose was to develop an aid system designed to prevent "chemical runaways" taking place along with their consequences at human level (death), environmental level (SEVESO type companies) and industrial level (destruction of installations).
This project follows an inquiry we made into a chemical runaway in a nuclear plant in 1994. The accident was fatal for one operator. In this case, two hours before the explosion, the operators realised that something was wrong. The five operators tried to get out of the unit a few seconds before the explosion. This type of result (which was largely confirmed by other analyses) shows that process operators often think that the time they have before an explosion is more than it really is. Our aim was the design of a system that would warn operators of the arrival of a chemical runaway and would predict the time remaining until an imminent explosion.

AIM AND OBJECTIVES OF THE RESEARCH

Design is a complex process and, in our case, it appeared necessary to dissociate two phases: (i) a first one, which comes under innovation, meaning the *design of the principle,* (ii) and a second phase which comes under *industrialisation of the principle,* meaning the implementation of the innovation in a given situation. The two stages have their own research objectives even though, in this communication, our objective is to deal with the industrialization phase.

An innovative system: The Chemical Runaway Detector/Forecaster (DPE).

The innovation consists of specifying an artefact of which a large number of examples will be used in multiple situations in life or at work. Therefore the challenge consists of dealing with the general case.
In our case, INERIS engineers developed a method for predicting the critical moment of chemical runaway. The method was implemented in a version called "DPE" -Runaway Detector/Forecaster - and tested in an experimental situation ("large scale" experiment) in order to assess its accuracy.

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Marss & Coll, 1989) analyzed the typology of around 200 accidents which took place in chemical reactors operating non-stop. The DPE is a system which detects around 60% of the accidents described in the Marss & Coll database. Sudden reactions (reactive loading error) or explosive reactions which take place in a few minutes (except for specific adaptation) are excluded from its scope. Naturally, the reliability of the information given increases if we have studies of the chemical kinetics of the expected reactions However, the kinetics of chemical runaways might not have been studied either due to the lack of a preliminary study or because of a minor change in the quality of a basic product. The most interesting aspect of the system is that, despite the lack of specific studies, it can assess the Time to Maximum Rate (TMR) with a moderate error level.

2.2 - From technical innovation to technology transfer

We have just seen that the innovation deals with the general. Industrialization is a much different phase which deals with the singularity of a given situation. It could be described as the phase of *"discovery of a company"*.

A considerable amount of research has shown the existence of contradictory organization and/or technical logics (De Terssac, G. 1992; Leplat, J. 1997). These logics can be converted into forms of latent error (Reason, J. 1990), meaning the presence of elements which can remain dormant for a long time and whose dangerous character most often only appears at the time of an accident (Reason, J., *op.cit.*). In this context, the control of technical systems should not only be considered as a negative factor but as a factor of reliability (Amalberti, R. 1996). Concretely, we wanted to know how and under what conditions the DPE would fit into the socio-technical system, including the cognitive functioning of operators and the use of systems placed at their disposal.

At the same time, examining the implementation of the artefact in existing structures is not fully satisfactory. The DPE is a technical system whose purpose is to make the socio-technical system reliable. Therefore, we also wanted to know if evolutionary dynamics existed following the introduction of the DPE and, if so, their conditions and limits.

And yet the industrialization of an innovation is a stage that is not very conceptualized. In ergonomics, the technology transfer has practically only been studied in the specific context of the modernization of an industrially developing country (Wisner, A. 1997). But for intra-national transfers, most of the work (done in France) concerned the socio-economic field. The main lesson learned from this research is that industrialization should be done systematically since the innovation cannot be defined simply in terms of technical bases. On the contrary, it is the environment of the installation which will determine if the technical system has an innovative character or not.

CHARACTERISTICS OF THE PILOT SITE AND METHODOLOGY

The DPE was introduced in a small catalyst production unit which produced synthetic optical lenses. The process of the pilot site (where industrialization took place) consisted of synthesizing a few dozen kilos of product from glass reactors. The operators were located beside the reactors which were installed in the "control room". The synthesis of the catalyst was exothermic: the temperature of the product could rise by itself. From the outset, the catalyst also started to self-destruct in an exothermic way by releasing secondary gaseous and explosive products (this is the "*chemical runaway*"). To prevent any chemical runaway, the catalyst is cooled during the synthesis by circulating glycolated water in coils placed in the reactors. In addition, its thermal and chemical homogeneity is ensured by agitators. Symmetrically, an excessive cooling can lead to cystallization of the product, preceded by an unstable "super-undercooling" phase. Between the solid state of crystallization and the gaseous state of chemical runaway, the product is liquid.

The industrialization of the DPE took place in two phases. An initial phase called "*exploratory study*" enabled us to characterize the socio-technical system of the pilot site. It lasted four months. During this stage, we used the Ergonomic Work Analysis (Wisner, A. 1995; De Keyser, V. 1991) which French-speaking ergonomists have developed over the last 30 years on the basis of the initial work of (Ombredane & Faverge, 1955). For reasons of objectivity, this involves the exhaustive recording of the behaviour of operators and the status of technical systems during execution of the action; on the basis of these observations, the operators are interviewed in order to obtain pertinent explanations, to validate the interpretations obtained from the observation and to generalize the results.

The purpose of the second phase, called "*experimental*", was to characterize the evolutionary dynamics. It lasted eight months. When it was introduced on the pilot site, the DPE had a digital temperature display, a TMR display for each of the reactors and visual and sound alarms which were activated for a given value of the TMR. Two types of methodology were used : Ergonomic Work Analysis and task simulation techniques. Concretely, the intention was to manipulate certain determinants of the action on the site and to analyze the activity of the operators in the situation created as such. In this case, simulation of the task was considered as a cognitive finality method (Simon, H. 1981) but also as an approach which could create situations of exchange among players with heterogeneous knowledge: designers, supervisors, operators and ergonomists (Béguin., P., & Weill Fassina, A. 1997).

CONTROLLING THE PROCESS WITH THE DPE

The "experimental phase" of introduction of the DPE highlighted paradoxical results. First of all, the operators consulted the artefact more and more often which, a priori, was positive. But an analysis showed that it was the temperature information provided by the DPE which was significant for the operators and not the TMR which actually constituted the interest of the system. The more the operators consulted the interface, the less they consulted the temperature indications which were provided previously (Cf. table 1). At the same time, fluctuations appeared in the TMR. This alerted the operators, indicating the existence of a danger they were obviously not aware of. But since they had no possibility of interpretation, this alarm made them perplex. This was considered as worrying by the operators but did not appear in the process control. How can this result be interpreted? An analysis of the socio-technical system provided some answers.

	1st week	2nd month	4th month
period during which information was read on the DPE	1.7%	8.1%	31.5%
period during which information was read on the analogue temperature indicators	27.3%	24.5%	4.2%

Table 1: Comparative development, during the experimental phase, of the period during which information was read on the DPE and the thermometers available previously (in % of the total control time). The DPE temperature was consulted more and more to the detriment of analogue indicators which are less accurate.

Control strategies and daily risks

The operators develop control strategies on the basis of the lower temperature threshold (super undercooling) and not on the basis of the upper threshold which corresponds to the TMR. This control strategy, very close to crystallization has several origins:

- First of all, the system should be kept at close as possible to the lower temperature threshold since experience shows that the colder the product during synthesis, the more the catalyst obtained will be of good quality from the physico-chemical viewpoint: the catalyst starts to self-destruct from the outset.
- Secondly, the characteristics of the technical system, in particular the system for cooling the product during synthesis, tend to spontaneously lead to super undercooling. In such a context; the operators are more inclined to let the temperature of the product rise than to take action to cool it.

Yet, process control very close to the low temperature threshold is a difficult exercise during which the skills of the operators develop. In this way, real crystallization theories were highlighted by an analysis of the activity. These are *theories for the action,* constructed during the work, whose purpose is to serve the action . The paradoxical result of the status which the operators give to the DPE information can thus be better understood:

- First of all, it is the temperature information that is used since it is part of the cognitive constructions and the uses already constructed by the operators. At the same time, the TMR appears external since what is important is not the TMR but what the TMR *indicates.* Yet, as we have just seen, in situation the operators develop knowledge which is far removed from the major risk constituted by chemical runaway. Therefore, it could be thought that they do not have all the cognitive instruments necessary to judge this information.

- Symmetrically, it is certain that control very close to super undercooling is less risky than a chemical runaway. But nevertheless it is considered by operators and their supervisors as a serious incident which should be avoided since, in one way or another, the product must be left to warm with all the risks linked to the instability of the polymer provoked by warming of the product. It could even be thought that, in this situation, chemical runaway could appear following super undercooling that was badly controlled.

Technical transfer and know-how transfer

These two aspects could be summarized by considering the introduction of the innovation as a technical and know-how transfer. The transfer was from the engineers to operators: the appearance of developments of the TMR required explanations concerning their significance. This was due to particular physico-chemical phenomena (micro chemical runaway) which appear in the reactor but do not require the implementation of emergency procedures. As such, training sessions were organized. The transfer also went from the operators (who develop singular knowledge which comes under "expertise" of crystallization) to the engineers: control very close to crystallization constitutes a good compromise. But it is not free of danger and there is a need for aid. In our situation, this vision led us to complement the principles of display of the temperature values provided to the operators. Initially, the temperature information was only given in a digital form. We kept this type of display since its accuracy corresponds to the requirements of the operators. But we added an analogue display with memory storage of the temperature curve. This facilitates the interpretation of the TMR (identification of "*micro chemical runaways*") and helps with control "*very close to super undercooling*".

FACING UP TO AND MANAGING THE UNKNOWN

Process control very close to super undercooling constitutes a class of situation that is well known to operators. But, as we underlined previously, a runaway could appear following a badly controlled super undercooling. Operators could then find themselves in another class of situation, the chemical runaway, which they know little about. Knowledge of the runaway in itself does not constitute the only element of doubt. The actions to be taken to deal with it are also relatively uncertain, both as regards the operators and the supervisory staff (security manager, foreman, methods manager, etc.) on the site. Here again, this is due to the lack of experience available.

One of these actions consists of "destroying the product", meaning that the reaction is inhibited by a chemical process and is evacuated using specific techniques and means Nevertheless, destruction of the product and the technical and organization conditions under which it is done, are problematic and uncertain since they are not really tried and tested. It should be noted that in the present situation, which has lasted for the 20 years that the site has been open, three "destructions" have taken place. In two cases, this followed technical problems (damage to equipment). In the third case, the problem was due to the production quality.

The DPE: a simulation tool

Since it provides information about the thermal kinetics of the product in the case of a chemical runaway, the DPE constitutes an opportunity to do a real test on the temporal conditions of the action consecutive to a chemical runaway. In this sense, we can use it like a simulation tool in order to explore the temporal conditions of a chemical runaway.

In the approach we used, simulation was done on the production in order to maintain all the physical and material characteristics. The main objective difference was the fact that the product contained in the reactors consisted of a chemically inert liquid. But the thermal kinetics of a chemical runaway were provided by the DPE. Computerized, recorded data of a chemical runaway in a laboratory were sent to the DPE which calculated the TMR on this basis. All the players liable to be present at the time of a chemical runaway were associated. The control operators, naturally, but also the foremen and the technical managers, who are usually not on the site, were also present.

An examination of the technical and organizational conditions

The most interesting part of this simulation approach concerned the production and implementation of the scenarios. In our study, several scenarios were produced but in all cases the approach used was the same: (i) initially a meeting was planned at which the scenarios were defined collectively, (ii) the scenarios were then implemented in situation by the operators and analyzed by the ergonomists and (iii) the approach ended with a debriefing. Each of these stages had a specific interest.

The interest of the meetings was that they led to the procedures being examined. This examination revealed certain ambiguities. For example, while the quality procedures indicated certain temperature values, the security procedures indicated other values even though the action to be done was the same. Yet the procedure which could be defined as *an operative procedure or method, designed to respond to a clearly defined situation,* constitutes an element whose existence is all the more important when the situation is rare and when action had to be taken in conditions of great time constraints with considerable consequences for production. All the conditions were present here.

The second stage, that of implementation of the action, had two interests. First of all, it was an opportunity for the operators to test, in action, an event that was too rare to be part of the local experiment. Secondly, it enabled the socio-technical system to be requestioned on the basis of execution of the action in an class of situation that was not well known. Let's take two examples. For one of the scenarios, it was considered, a priori, that three operators were necessary to perform the action. The simulation showed that, on the contrary, six persons were required. This figure corresponds to the number of persons who should be allocated to the site and be permanently present, which was not the case. This last point deserves to be theorized. The testing of the action, under chemical runaway conditions that are not well known, would reveal latent errors that were present on the site but not identified for a class of situation which was made rare by the activity of the operators.

Finally, the debriefing also had two interests. First of all, it was an opportunity to transfer the knowledge of the engineers (present on the site) to the operators. Since it is a source of surprise, testing of the runaway conditions in action generates beneficial debates and exchanges. Secondly, the treatment of latent errors was facilitated by the presence of the supervisory staff on the site. It should be noted that each simulation ended with action decisions which concerned either the procedures, the technical conditions or, finally, the organizational conditions.

DISCUSSION

The industrialization of an innovation constitutes a stage is that little conceptualized. First of all, it could be considered as an adjustment of the artefact on the basis of a confrontation with reality. Nevertheless, our results show that this should be renewed for each installation of the DPE. One of the strategic aspects of industrialization concerns the evolutionary dynamics implemented through the impetus of introduction of the artefact. Yet the main result of this research actually concerns the need to manage the said dynamics at two levels.

The first level concerns adaptation of the artefact to the singular. The innovation is based on theoretical knowledge, built on the basis of hypothetical and deductive approaches which come under the expertise of engineers and can be very generalized. Yet, in our situation, the operators could be described as the experts of a singular process, that in which they worked for several years: they have very situated knowledge, marked by the socio-technical system of a given company. Introduction of the DPE brings face to face very generalizable scientific concepts - which may have little to do with the site - and the control strategies used which make the operators experts in their work situation. But this is an expertise which concerns the most frequent conditions of control. Industrialization consists of putting this heterogeneous knowledge in tune. This process of exchange generates creation which is liable to be translated at the level of the artefact. In our situation, it is the said dynamics which led to an in-depth change in the criteria and principles of the display of values provided to operators by the artefact. But we consider that, in other situations, other adjustments could be desirable.

The second level more generally concerns risk management We know that some industrial accidents are due to system defects in their technical and organization dimensions. These are the defects which (Reason, J. 1990) suggested calling "Latent errors". Nevertheless, they can only be expressed in classes of situation that are very specific when the activity of the operators is found to be lacking, which is very rare. The main question then does not so much concern the imputation of responsibility (which is the question at the origin of the "latent error") as the ways and means of identifying the "latent risks". Certainly, the DPE is a system which can warn operators of an imminent chemical runaway. But, during the study, it also appeared to be a system which, in the case of a certain type of accident (chemical runaway), provides the opportunity to requestion the socio-technical system as regards unknown classes of situation. In this sense, it could be used as a means of revealing latent risks in a given situation.

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